REFRACTIVE INDICES OF OVERFIRE SOOT IN LARGE BUOYANT TURBULENT DIFFUSION FLAMES

by

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Introduction. Information about the optical properties of soot is needed in order to develop reliable nonintrusive measurements of soot physical properties and estimates of soot radiation properties in flame environments. Unfortunately, current estimates of soot optical properties are limited by excessive uncertainties about soot refractive indices [1]. Motivated by this observation, the objective of the present investigation was to experimentally determine soot refractive indices at visible wavelengths (350-800 nm). Soot in the overfire region of buoyant turbulent diffusion flames in the long residence time regime (where soot properties are independent of position and residence time [2]) was studied, considering flames fueled with acetylene, propylene, ethylene and propane burning in still air.

Experimental Methods. The soot was produced by a round, water-cooled burner exhausting into a large collection hood (heated to minimize soot deposition) followed by a short exhaust duct. Soot properties were measured at the exit of the exhaust duct. Soot physical properties were found by collecting samples thermophoretically and analyzing them by pychnometry to find soot density, by ultimate analysis to find elemental composition and by transmission electron microscopy (TEM) to find soot structure. Soot volume fractions were measured by weighing soot collected on a filter while measuring the volume flow of gas over the collection period; this information, combined with the known soot density, yields soot volume fractions at the test location.

Soot refractive indices were found from measurements of soot scattering properties in conjunction with the gravimetric determination of soot volume fractions. Measured scattering patterns were successfully correlated using Rayleigh-Debye-Gans scattering theory for polydisperse fractal aggregates (denoted RDG-PFA theory) that has been shown to be effective for soot optical properties [1-4]. These results then yielded the real and imaginary parts of the refractive indices and the dimensionless extinction coefficients of soot in a straightforward manner [5].

Results and Discussion. Present measurements confirmed that RDG-PFA theory was effective for treating the optical properties of soot for the present conditions; this is important because the test range reached primary particle optical diameters as large as 0.42, which severely tests the approximations of RDG-PFA theory [5].

Present measurements of the real and imaginary parts of the refractive indices of soot are plotted as a function of wavelength, with fuel type as a parameter, in Fig. 1. Also shown on the figure are *ex situ* reflectometry measurements for soot in fuel-lean regions of acetylene and propane/air diffusion flames [6,7], *in situ* measurements for soot in fuel-lean plexiglass/air diffusion flames [8], and *in situ* measurements for soot in the post-flame region of fuel-rich premixed propane and ethylene/air flames [9,10]. Present soot refractive indices do not vary significantly with fuel type and are in reasonably good agreement with the often criticized early measurements of Dalzell and Sarofim [6]. On the other hand, the other measurements [7-10] can be criticized because they involve questionable models of the optical and aggregate properties of soot, while some use questionable approximations when applying Drude-Lorenz dispersion models or Kramers-Krönig causality relationships to close procedures to find soot refractive indices. In particular, present results do not approach a resonance condition typical of graphite as the uv is approached, which is assumed in some refractive index determinations; instead, refractive indices decline continuously similar to the observations of Vaglieco et al. [10] for amorphous carbon and soot.

Present measurements of dimensionless extinction coefficients are plotted as a function of wavelength, with fuel type as a parameter, in Fig. 2. Also shown on the figure are earlier measurements

of this parameter for soot in the overfire region of crude-oil/air diffusion flames [11] and in the post-flame region of premixed fuel-rich acetylene/air flames [12]. Present measurements exhibit little variation with fuel type and wavelength and yield a mean value of 5.1 [5]; this value is smaller than the values of 8.1-9.4 found earlier [11,12], however, for reasons that still must be explained.

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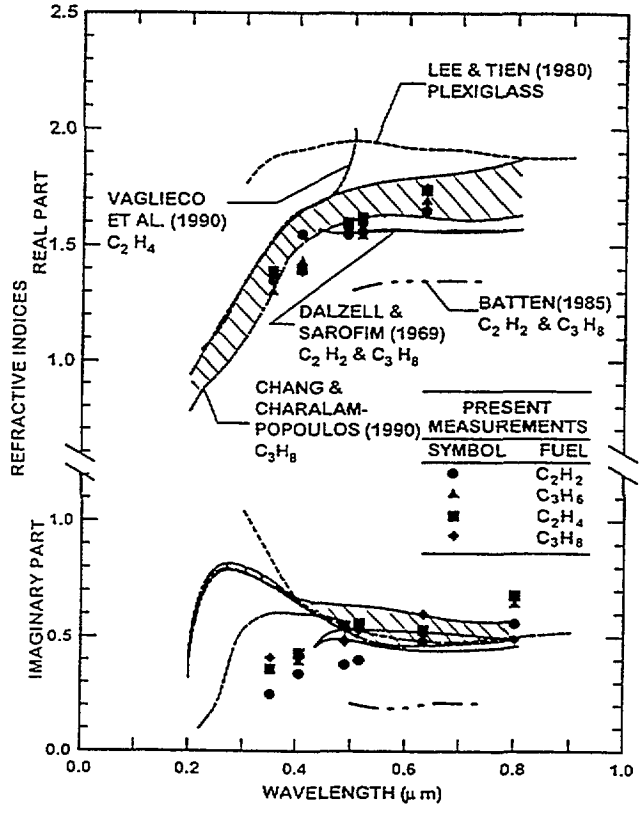

Fig. 1 Measured soot refractive indices.

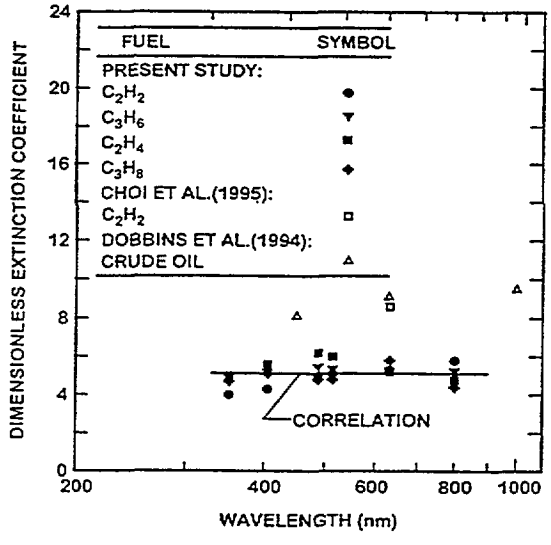

Fig. 2 Measured soot dimensionless extinction coefficients.